Trade-offs between yields, forage quality and botanical diversity in permanent grasslands of the Vosges Mountains in France

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Abstract

Assessing trade-offs between forage production and ecological characteristics delivered by grasslands is a growing concern for stakeholders and scientists. We sampled 50 grasslands from the Vosges Mountains (north-eastern France), and measured the agronomic (forage yield and quality) and biodiversity characteristics of each grassland. We assessed yield through dry matter production; fodder quality through organic matter digestibility, protein, energy and mineral content; and biodiversity through total and oligotrophic plant species richness and ecological indices. Using a Hierarchical Clustering on Principal Components, our results show that grasslands can be classified into three classes. The first class is made of grasslands associated with high quality forage but poor ecological value, the second of diverse and productive grasslands associated with poor forage quality, and the last one of grasslands and moors of high ecological value but poor forage yield and quality. These classes are mainly determined by agricultural practices and soil properties. Our study highlights the trade-offs between the agronomic and ecological characteristics of grasslands: grasslands cannot produce high yields, qualitative forage and protect biodiversity at the same time. We argue that agronomists and naturalists must work together at both farm- and landscape-scales to produce forage in sufficient quantity and quality while protecting biodiversity.

Keywords: yield, forage quality, species diversity, agroecological characteristics, soil

Introduction

Permanent grasslands provide diverse agroecological characteristics of global importance, such as forage production and species habitat. It is generally accepted that grasslands can either produce high quantity of forage or support biodiversity. Indeed, grasslands are mainly fertilised to increase yield, which decreases botanical diversity as side-effect. Conversely, the effects of biodiversity on yield is still debated: no agreement has been found with regard to permanent grasslands (Li *et al.*, 2019). Forage from unfertilised grasslands (Aydin and Uzun, 2005) and species-rich grasslands (French, 2017) could have higher quality due to the presence of legumes. So far, few studies have considered forage yield, forage quality and biodiversity simultaneously in order to study trade-offs and synergies. Moreover, biodiversity is often only studied in terms of species richness, without interest in the ecological value of different species. We hypothesized that yield is negatively correlated to forage quality and diversity of vascular plants.

Materials and methods

We studied botanical composition of 50 grasslands (complete list of species of the main vegetation community, contribution to biomass of species in 6 plots 70×70 cm) a few days before their first utilisation, in the Vosges Mountains (north-eastern France). Climate and geology vary through the influence of latitudinal, longitudinal and altitudinal gradients.

The first aim of this study was to analyse trade-offs between grassland characteristics. We assessed yield through dry matter production; fodder quality through organic matter digestibility, protein, energy and mineral content; and biodiversity through total plant species richness, diversity indices and oligotrophic species richness as proxy of preservation of patrimonial habitats. We used a Hierarchical Clustering

on Principal Components (HCPC) to observe trade-offs among characteristics. The second aim was to identify the determinants of the trade-offs, so we added determinants related to environment, management and vegetation to the HCPC as supplementary variables.

Results and discussion

The five first components explained 85.3% of the variance, and the classification produced three classes of grasslands. The first class regrouped 15 grasslands, the second class 27 grasslands and the third class 8 grasslands. Characteristics and determinants related to each class are described in Table 1.

The second class highlighted a positive correlation between biodiversity and yield, which is still largely debated: yield could be more influenced by key species or traits than biodiversity (Mahaut *et al.*, 2020). However, the second class confirmed the negative correlation between diversity and digestibility (Hofmann and Isselstein, 2005), but contrasted with studies demonstrating synergy between diversity and protein content (Aydin and Uzun, 2005; French, 2017). This class also confirmed that mowing and late use improve botanical diversity (Fischer and Wipf, 2002).

The third class showed trade-offs between total botanical diversity and oligotrophic species richness, highlighting that species richness is not necessarily a useful indicator of ecological value (Pykälä *et al.*, 2005). This class also confirmed that oligotrophic species are favoured by poorly fertilised grasslands (Garnier *et al.*, 2018), but contrasted with previous studies assuming that legumes are favoured by weakly fertile soils (Suding *et al.*, 2005).

Table 1. Results of grassland classification (HCPC).[1]

			Class 1	Class 2	Class 3	Overall mean
Characteristics	Quantity	Yield (Mg ha^{-1})	-	**2.1**	1.0	1.8
	Quality	Digestibility (%)	**74**	64	-	67
		Protein	**63.0**	55.7	54.0	57.6
		Energy	**0.98**	0.81	-	0.86
		Ca	**0.74**	-	0.36	0.61
		K	**2.54**	1.57	1.36	1.82
		Mg	**0.29**	-	0.17	0.23
		P	**0.34**	0.20	-	0.24
	Plant diversity	Total richness	-	**32.3**	23.1	30.5
		Shannon index	-	**3.56**	2.66	3.36
		Simpson index	-	**0.88**	0.76	0.85
		Oligotrophic richness	5.6	-	**9.7**	7.1
Determinants	Climate	Mean temperature (°C)	-	-	8.5	9.3
	Soil	Clay (%)	-	**20.8**	-	17.7
		Silt (%)	-	**34.8**	-	30.8
		Sand (%)	-	44.6	**64.1**	51.6
		pH	-	**5.9**	4.8	5.6
	Management	Date of 1st use (heat unit)	605	**1,035**	-	910
		Cut/grazing	-	**0.80**	-	0.63
	Soil + management	C/N	-	-	**12.8**	11.7
	Vegetation	Legumes (%)	-	-	4.0	9.9

[1] Characteristics and determinants significantly related to each class ($P<0.05$) are shown. In bold, values that are above overall mean.

First and third classes underlined trade-offs between oligotrophic species richness and forage yield or quality, which could cause difficulties to conserve these species already threatened by intensification (Garnier *et al.*, 2018). Finally, first and second classes confirmed that early use of grasslands increases forage quality (Bruinenberg *et al.*, 2002). In the present study, forage quality did not include the quality of products like milk, cheese and meat, nor animal health. These characteristics could affect the trade-offs between botanical diversity and forage quality, as they are improved by diversity (Martin *et al.*, 2005; Poutaraud *et al.*, 2017).

Conclusions

Our study highlighted the trade-offs between agronomic and ecological value of grasslands. Grasslands could not produce high yields, quality forage and protect botanical diversity at the same time. Soil and management mainly determined these trade-offs. Agronomists and conservation scientists must work together at both farm- and landscape-scales to find solutions for producing forage of sufficient quantity and quality while protecting biodiversity.

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